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ESTIMATION AND IDENTIFICATION FOR MODELING DYNAMIC SYSTEMS.(U)
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ESTIMATION AND IDENTIFICATION FOR

MODELING DYNAMIC SYSTEMS

INTERIM REPORT

AFOSR GRANT 75-2797

March 1, 1977 - February 28, 1978

by

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Research Associate Professor of Electrical Engineering

I. INTRODUCTION

Systems are modelled in order to understand and explain them better and as a prelude to action. Aircraft dynamics, for example, may be identified so that better designs can be made, or so that adaptive control actions can be taken. Our attention in this continuing study has been directed at aspects of estimation and identification that are connected with system understanding. This study has been aimed at two problem areas: multistage modeling, estimation, and identification algorithms for dynamical systems, and, state estimation and a parameter identification for a new class of models -- causal functional equations -- which describe wave propagation in layered media systems.

The first problem is concerned with developing estimation algorithms both for parameter and state estimation that are recursive in the dimension of the parameter vector or state vector. Such algorithms will find utility in system modeling work, where model dimension is often a variable.

The second problem is concerned with developing whole new theories of state estimation and parameter identification for a new class of equations which we refer to as causal functional equations. These equations are continuous-time linear, time-invariant with multiple time delays. They do not contain derivatives or integrals, and no literature apparently exists for them. Causal functional equations are applicable to diverse areas such as reflection seismology, transmission lines, speech processing, optical thin coatings and EM problems.

During the Summer of 1977, Dr. Keith Glover spent six weeks working on this grant as a Visiting Research Scholar.

II. RESEARCH PROGRESS

1. We have demonstrated that it is possible to extend Friedland's [A] bias estimation technique, as recently rederived in a constructive manner by Mendel and Washburn [1], to the problem of estimating dynamical states and colored noise states [2]. We have shown how to obtain an exact multistage

decomposition not only for the state estimation equations, but also for the associated error covariance equations. Additionally, we have obtained a second-order suboptimal multistage estimator, using a perturbation technique. Whereas a high-order matrix Riccati equation must be solved when the exact results are used, a matrix Riccati equation, of the dimension of the colored noise states, must be solved when the sub-optimal results are used.

2. Washburn [3, 4] has generalized Friedland's [A] bias estimation technique to partitioned dynamical systems. In the general case, the calculations are of the dimension of the overall system, so that, except for some special but important cases, there are no computational advantages to the multistage approach. Those special cases, where there does appear to be computational advantages for the multistage approach are: colored noise (discussed above in Item 1) and weak coupling between the partitioned systems.

The general results are important in themselves, since they provide the theory for a particular decomposition of the optimal state estimator for a system of possibly large dimension (i. e., a large scale system). This decomposition gives added insight into the structure and performance of the minimum variance unbiased estimator. In addition, the methodology of proof for this multistage decomposition provides a means for investigating other decompositions of interest.

<u>Under the present grant we have completed our study into the development of multistage Kalman/Bucy filters for linear lumped parameter dynamical systems.</u>

3. We have developed time-domain state space models for lossless layered media which are described by the wave equation and boundary conditions [5, 6]. Our models are for non-equal one-way travel times; hence, they are more general than existing models of layered media which are usually for layers of equal one-way travel times. Full state models, which involve 2K states for a K-layer media system, as well as half-state models, which involve only K states have been developed and related. Certain transfer functions, which appear in the geophysics literature in connection with models of layered media

with equal travel times have been generalized to the situation of non-equal travel times. Our state space models represent a new class of equations, causal functional equations, for which we have not been able to find any literature. These equations are continuous-time, linear, and contain multiple time-delays. Their impulse response is an infinite sequence of non-uniformly spaced impulse functions.

4. We have proven the truth [7, 8] of the following decomposition of the solutions to the lossless wave equation in layered media: the complete output from a K-layer media system, which is comprised of the superposition of primaries, secondaries, tertiaries, etc., can be obtained from a single state space model of order 2K -- the complete model -- or from an infinite number of models, each of order 2K, the output of the first of which is just the primaries, the output of the second of which is just the secondaries, etc. This decomposition of the solution to the lossless wave equation into physically meaningful constituents (i. e., primaries, secondaries, etc.) is called a canonical Bremmer Series decomposition, after Bremmer, who in 1951 established a similar decomposition [B].

In many geophysical situations, where reflection coefficients are quite small, the decomposition can be truncated after secondaries or tertiaries; hence, it also represents a way to approximate the solution to the wave equation .

We have made connections [9] between our state space models and the integral equations given by Bremmer [B] for generating the partial residuals.

We have shown how to go from Bremmer's integral equations to our state equations by assuming a medium with a wave number that has finite jumps (discontinuities) which occur at the interfaces and that is constant within a layer. These assumptions for wave number are associated with what we mean by a horizontally layered homogeneous earth.

We have also demonstrated that Bremmer's integral equations can be obtained by the W. K. B. method which gives approximate solutions to second-order differential equations [C]. This justifies earlier claims [7, 8] that the Bremmer series decomposition can be used to approximate the complete solution to the lossless wave equation by truncating that decomposition after a small number of terms.

5. We have developed [10] a general theory for describing reinforced events between multiple reflections in lossless layered media, which are described by the wave equation and boundary conditions (e. g., horizontally stratified nonabsorptive earth with vertically traveling plane compressional waves).

Reinforcements occur whenever two or more multiple reflections from different paths inside the media arrive at the surface at the same time so that they add (positively or negatively) together. Those reinforcements occur regardless of what the travel time is in each layer, and distort the appearance of a seismogram; for, they lead one to believe that a significant event has occurred by the appearance of a large amplitude segment of the seismogram, whereas, in reality, that large event is a sum of (many) smaller events.

Our general theory is applicable to a K-layer media system with non-uniform travel times and gives information about the exact location in time, number, and amplitude of reinforced events for n-aries (i. e., secondaries, tertiaries, etc.), where n = 1, 2, 3, ... The starting point for the development of this theory is Mendel's Bremmer series decomposition [7, 8] and the operator description of state space models of layered media [5] by means of which n-ary reflections (where n = 1, 2, 3, ...) are generated and analyzed separately and related to each other. The two most significant multiple reflections, secondaries, and tertiaries, have been studied extensively. We have demonstrated that not only do reinforcements occur between the same kind of multiple reflections (e. g., between secondaries), but that reinforcements also occur <u>across</u> different kinds of multiple reflections (e. g., between secondaries and tertiaries).

6. Because our causal functional state space models for a layered media system represent a new class of equations, we have had to study the computer simulation of these equations. Two computational methods have been considered [11]. In the first approach, we discretized the time axis and inserted states of intermediate delays, to arrive at a set of standard finite-difference equations. For our particular system, matrix multiplications can be reduced to simple scalar multiplications. In the second approach, we

defined mapping rules for the transformation of states at an interface, and kept a state reference table for look-up and branching. The procedure is similar to ray-tracing. Several experiments have been performed to show the trade-off between storage requirement and CPU time-spent for the two methods.

7. We have developed a procedure for extracting reflection coefficients from noise data [12] which we feel is a substantial generalization of similar procedures which have been reported in the literature ([D] for example). Associated with these earlier procedures are Standard Assumptions and Steps which include requirements that the data be noise free and that the observed seismic data be deconvolved. Our procedure avoids these restrictive requirements. Furthermore, our procedure totally avoids the concepts of z-transforms, minimum phase, spectral factorization, forward and reverse polynomial manipulations, etc., which appear in the literature on this subject.

8. Several state space realizations of seismic source signatures were obtained using approximate realization methods. This work was performed by Dr. Keith Glover who spent six weeks at the University of Southern California, as a Visiting Research Scholar, during the Summer of 1977.

PUBLICATIONS UNDER GRANT 75-2797

1. J. M. Mendel and H. D. Washburn, "Multistage Estimation of Bias States in Linear Systems," accepted for publication in Int. J. on Control.

2. H. D. Washburn and J. M. Mendel, "Multistage Estimation of Dynamical and Colored Noise States in Continuous-Time Linear Systems," submitted for publication.

3. H. D. Washburn, "Multistage Estimation and State Space Layered Media Models," Ph.D. Dissertation, March 1977.

4. H. D. Washburn and J. M. Mendel, "Multistage Estimation of Dynamical and Weakly Coupled States in Continuous-Time Linear Systems," submitted for publication.

5. J. M. Mendel, N. E. Nahi, L. M. Silverman, and H. D. Washburn, "State Space Models for Lossless Layered Media, presented at 1977 Joint Automatic Control Conference, San Francisco, California, June 1977.

6. J. M. Mendel, N. E. Nahi and M. Chan, "Synthetic Seismogram Using the State Space Approach," submitted for publication.

7. J. M. Mendel, "A Canonical Bremmer Series Decompostion of Solutions to the Lossless Wave Equation in Layered Media," presented at 1977 Joint Automatic Control Conference, San Francisco, California, June 1977.

8. J. M. Mendel, "Bremmer Series Decomposition of Solutions to the Lossless Wave Equation in Layered Media," IEEE Trans. on Geoscience Electronics, Special Issue on Seismic Data Processing, April 1978.

9. J. M. Mendel and F. Aminzadeh, "On the Bremmer Series Decomposition of Solutions to the Lossless Wave Equation in Layered Media," submitted for publication.

10. J. M. Mendel and J. S. Lee, "Reinforcement of Reflections," presented the 47th Annual International Meeting of the Society of Exploration Geophysicists, Calgary, Canada, September 1977.

11. W. M. Chan, N. E. Nahi, and J. M. Mendel, "Computational Solutions to a Non-Uniform Time-Delay Linear System," presented at Symposium on Applications of Computer Methods in Engineering, University of Southern California, Los Angeles, California, August 1977.

12. N. E. Nahi, J. M. Mendel and L. M. Silverman, "Recursive Derivation of Reflection Coefficients from Noisy Seismic Data," presented at 1978 IEEE Int'l. Conf. on Acoustics, Speech, and Signal Processing, Tulsa, Oklahoma, April 1978.

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[C] R. Bellman and R. Kalaba, "Functional Equations, Wave Propagation, and Invariant Imbedding," J. Math. and Mech., Vol. 8, pp. 683-704, 1959.

[D] E. A. Robinson and S. Treitel, "The Spectral Function of a Layered System and the Determination of the Waveforms at Depth," Geophysical Prospecting, 1977.

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Systems are modelled in order to understand and explain them better and as a prelude to action. The study has been aimed at two problem areas: multi-stage modelling estimation & identification algorithms for dynamic systems, and state estimation and a parameter identification for a new class of models -- causal functional equations -- which describe wave propagation in layered media systems. The first problem is concerned with developing estimation algorithms both for parameter and state estimation that are recursive in the dimension of the parameter vector or state vector. The second problem is concerned

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is referred

20. Abstract

with developing whole new theories of state estimation and parameter identification for a new class of equations which we refer to as causal functional equations. Eight new papers were submitted or accepted for publication.

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